Title: The reproducibility and external validity of a modified rugby league movement simulation protocol for interchange players.

ABSTRACT

Purpose: The study assessed the reliability and external validity of a rugby league movement simulation protocol for interchange players that was adapted to include physical contact between participants

Methods: Eighteen rugby players performed two trials of a modified rugby league movement simulation protocol for interchange players (RLMSP-i), seven days apart. The simulation was conduced outdoors on artificial turf with movement speeds controlled using an audio signal. Micro-technology was used to measure locomotive and accelerometer (i.e. PlayerLoad^{TM}) metrics for both bouts (~23 min each) alongside heart rate and RPE.

Results: Reported for each bout, total distance (102 ± 3 and 101 ± 3 m·min^{-1}), low-speed distance (77 ± 3 and 79 ± 4 m·min^{-1}), high-speed distance (25 ± 3 and 22 ± 4 m·min^{-1}), PlayerLoad^{TM} (10 ± 1 and 10 ± 1 AU·min^{-1}), PlayerLoad^{TM} slow (3.2 ± 0.6 and 3.2 ± 0.6 AU·min^{-1}), PlayerLoad^{TM} 2D (6.0 ± 0.9 and 5.7 ± 0.8 AU·min^{-1}) and heart rate (86 ± 5 and 84 ± 6 %HR max) were similar to match play. The coefficient of variation (%CV) for locomotive metrics ranged from 1.3 to 14.4%, accelerometer CV% 4.4 to 10.0%, and internal load 4.8 to 13.7%. All variables presented a CV% less than the calculated moderate change during one or both bouts of the simulation except high-speed distance (m·min^{-1}), %HR$_{peak}$ and RPE (AU).

Conclusion: The modified RLMSP-i offers a reliable simulation to investigate influences of training and nutrition interventions on the movement and collision activities of rugby league interchange players.

Keywords: team sport, collision, reliability

INTRODUCTION

Controlled match simulations have been developed for rugby league that replicate the movement activities of both whole match[1] and interchange players.[2] Simulations are useful given the large inter-match variation observed as a result of the technical and tactical demands of competitive rugby league performance.[3] Conversely, match simulations are adequately reliable[4.5] for the investigation of the influence of physical contact on performance,[6] nutritional interventions,[7] knowledge of task end-point on pacing strategies[8] and the metabolic requirements of performance.[9]

Despite possessing acceptable validity and reliability for locomotive demands, previous attempts to simulate the match demands of rugby league have resulted in similar heart rate responses but greater relative distance and high speed running compared to match play.[5] The replication of collisions in the original simulation using a padded (~30 kg) tackle bag impaired the external validity of such simulations.[6,9] The use of a tackle bag to replicate contact also increases the overall running speed as a consequence of a faster approach to the collision and results in less neuromuscular fatigue when compared to a heavier tackle sled.[10] Lastly, substrate use, assessed via muscle glycogen depletion, of simulated match play with a tackle bag is also much lower when compared to actual match play.[9] Therefore, further attempts to adequately replicate contact during the rugby league movement simulation protocol, whilst maintaining the reliability of physiological, perceptual and performance responses, are required.

PlayerLoad™ is derived from a triaxial accelerometer embedded within a wearable microtechnology device. The variable is calculated from the instantaneous rate of change of acceleration in three planes of motion; longitudinal, medio-lateral and anterior-posterior. PlayerLoad™ is a reliable measure[11, 12] and positively correlated with treadmill running velocity,[12] total distance and collisions.[13] Further, PlayerLoad™ variations can be calculated including two-dimensional PlayerLoad™ (PlayerLoad™ 2D; medio-lateral and anterior-posterior only) and PlayerLoad™ slow (all accelerations that occur at < 2 $m \cdot s^{-1}$). Such markers appear able to quantify rugby rugby-specific activities, such as wrestling and grappling, and have been shown to discriminate between positions during match play.[13,14] However, the reliability of such metrics during intermittent running interspersed with physical collisions is still unknown.

While simulations provide a useful tool to analyse specific match actions in rugby league, adaptation of the existing protocol is required to replicate the physiological load of competitive matches. Therefore, the aims of this study were to: a) confirm the reliability of these measurements in the context of relevant analytical goals and b) compare the locomotive and physiological responses to modified physical contact during the RLMSP-i with previous protocols and match data.

METHODS

Participants and design

Eighteen sub-elite rugby players (age: 18 ± 1 y, stature: 1.80 ± 0.08 m, mass: 87.9 ± 11.8 kg) performed two trials of a modified version of the previously described RLMSP-i[5] separated by one week. The participants were asked to record their dietary intake in the 24 hours before the first trial and repeat this intake in the 24 hours before their second trial, which was verified by the lead researcher. Participants were asked to refrain from strenuous exercise and consumption of ergogenic supplements (e.g. caffeine) 24 h hour before each trial. Both trials were performed against the same opponent, at the same time of day (± 1 hour) on the same synthetic grass outdoor pitch in similar environmental conditions (14.4 ± 0.6°C; THG810, Oregon Scientific Ltd., Berkshire, UK). All participants provided written informed consent and were free from injury at the time of testing. The Faculty of Life Sciences Research Ethics Committee granted ethics approval for the study.

Participants were habituated to the simulation before each trial, comprising three cycles of the simulation that lasted approximately 6 minutes, and given verbal instructions on the protocol requirements. During the match simulation, participants' locomotion, tri-axial accelerometer load, HR and RPE were measured.

Procedures

Rugby league movement simulation protocol for interchange players

After a standardised warm-up, participants moved between a linear series of cones, with movement speed controlled by an audio signal. Two bouts of 23 min activity were interspersed with a 20 min passive recovery period to simulate the mean playing time of elite interchanged rugby league players.[2] Each bout was identical and consisted of 12 repeated cycles that combined locomotive and physical contact activity. Briefly, the simulation was designed to reproduce total relative running demands of ~100 $m \cdot min^{-1}$, ~1 physical contact per minute and mean HR of 85-90 $\%HR_{peak}$.[15] Figure 1 provides a schematic of the RLMSP-i and the ordering of the audio cues.

*****Insert Figure 1 about here*****

Contact was modified from that described by Waldron and colleagues[5] to involve a collision between two participants that were matched for body mass. The collision event comprised one participant performing a defensive tackle on their opponent who moved towards the attacker holding a tackle shield. Both participants were instructed to sprint 8 m towards their opponent and contact the tackle shield at torso height with their shoulder. At the point of contact the participant was instructed to wrap their arms around the tackle shield and their opponent and attempt to turn 180° to gain dominance whilst their opponent resisted. After three seconds the researcher called "held" and both participants were instructed to perform a “flapjack” exercise to replicate the change of orientation associated with completed tackles. The flapjack exercise involved dropping into a prone position on the ground before rolling laterally 360° to the left and then rolling back to the original position before returning to their feet. In the second contact in each cycle, participants alternated from offensive (holding the tackle shield) to defensive (performing the tackle) contacts. Participants performed 24 defensive and 24 offensive efforts over the duration of the simulation.[5]

Movement characteristics of each participant were recorded using a 10 Hz GPS device with an embedded 100 Hz triaxial accelerometer, magnetometer and gyroscope (Optimeye S5, Catapult Innovations, Australia). The device was fitted into a custom designed vest that was securely positioned between the participant’s scapulae. Total distance per minute ($m \cdot min^{-1}$), high- and low-speed running distance per minute (≥ 14 $km \cdot h^{-1}$ and < 14 $km \cdot h^{-1}$, respectively; $m \cdot min^{-1}$), peak speed ($km \cdot h^{-1}$), total PlayerLoad™, two-dimensional PlayerLoad™ (PlayerLoad™ 2D) and PlayerLoad™ slow were recorded and the ratio of PlayerLoad™ slow to total PlayerLoad™ (PlayerLoad™ slow-ratio; %) was calculated for each bout of the simulation. All external load data was analysed using the manufacturer’s software (Sprint, Version 5.1, Catapult Sports, Australia). These metrics were selected on the basis of their appropriateness for quantifying movements and activities of collision sports.[13]

HR was recorded with a HR monitor (Polar Electro, Oy, Finland) wirelessly paired to the micro-technology device and fitted around the participants' chest. HR data was analysed (Sprint, Version 5.1, Catapult Sports, Australia) as a percentage of the participant's peak HR (%HR_{peak}) determined from the maximum value attained during the simulation protocol. RPE (6-20)[16] was retrieved at the end of each bout of the match simulation.

Statistical analysis

Absolute reliability was assessed using Typical Error (TE; calculated as the standard deviation (SD) of the differences (diff) between trial 1 and trial 2 divided by √2.) and coefficient of variation (CV%; calculated as; (SD diff/√2) / (grand mean) x 100).[17] The smallest worthwhile change (SWC; 0.2 x between participant SD/grand mean), moderate change (MC; SWC x 3) and large change (LC; SWC x 6) were determined to provide an analytical goal for reliability (i.e. measurement error should be lower than these meaningful changes to have sufficient confidence that they are 'real'). All calculations were completed using a predesigned spreadsheet.[18]

RESULTS

No variable resulted in a CV% smaller than the SWC. All variables presented a CV% less than the calculated MC during one or both bouts of the match simulation except from high-speed distance ($m \cdot min^{-1}$) during bout 1 (8.0% c.f. 7.0%) and bout 2 (14.4% c.f. 10.3%), HR (%HR_{peak}) during bout 1 (4.8% c.f. 4.4%) and bout 2 (7.0% c.f. 5.8%) and RPE (AU) during bout 1 (13.7% c.f. 8.9%) and bout 2 (11.2% c.f. 6.7%). In all of these exceptions, the CV% was smaller than the LC. All data are presented in Table 1 and 2.

***** Insert Table 1 here *****

***** Insert Table 2 here *****

Measures of total distance, low-speed distance, high-speed distance, PlayerLoad™, PlayerLoad™ slow, PlayerLoad™ 2D and heart rate during the simulation are reported in Table 3 with comparisons to the original RLMSP-i and match play.

***** Insert Table 3 here *****

DISCUSSION

The reliability of certain external load variables during this modified rugby league movement simulation protocol are comparable with those presented originally by Waldron et al.[5] for total distance (CV% = 1.1 c.f. 1.3%), low-speed distance (CV% = 1.2 c.f. 2.2%) and peak speed (CV% = 2.0 c.f. 3.7%). Furthermore, the typical error for total distance (1.4 $m \cdot min^{-1}$ in Bout 1) is less than the observed difference between contact and non-contact match simulation trials (3-4 $m \cdot min^{-1}$)[6] and the reduction reported during match play from quartile 1 to quartile 4 (~11 $m \cdot min^{-1}$)[2]. The modified match simulation provides a model with sufficient reliability to accept moderate changes in these particular external load measures as ‘real’ (i.e. due to an intervention and not the inherent variability of the test).

The CV% for high-speed running distance is larger in the current study compared to Waldron and colleagues[5] during Bout 1 (CV% = 8.0 c.f. 2.9%) and Bout 2 (CV% = 14.4 c.f. 5.5%). The greater variability during the modified protocol is likely due to the modification to simulated contact. While the traditional tackle bag used by Waldron et al.[5] did not fully replicate physiological demands associated with competitive matches, the task is highly controlled and repeatable. In contrast, the tackle shield method in the present study is heavily reliant on participants' performance and can be influenced by individual variation in tackle technique. For example, effective tackles include contacting the opponent near their centre of gravity, effective use of the shoulder, well aligned body position to the opponent, leg drive upon contact, careful observation of the opponent's movements and effective weight transfer through the tackle.[19] The greater number of variables when tackling an opponent is likely to increase variability compared to collisions with a tackle bag. Furthermore, as players fatigued during the protocol, it is also likely that tackle technique deteriorated,[19] adding further to the variability of the modified collision. The type of contact has been shown to influence sprint behaviour[6,10] and therefore variation in tackle performance is likely to result in greater variability in high-speed running performance compared to the previous match simulation. These issues notwithstanding, the variation between trials observed for the modified simulation protocol remains less than that between competitive matches for high-speed running above 15 $km \cdot h^{-1}$ during the first (CV% = 20.4%) and second half (CV% = 23.1%).[3] Furthermore, the variation between trials is less than changes in distance covered (7-20%) and high intensity running (10-32%) associated with adding contact to small-sided games,[20] supplementing caffeine[7] and manipulating pacing strategies.[8] Consequently, this modified protocol is sufficiently reliable to detect previously observed changes in running performance and could be incorporated into future intervention studies.

PlayerLoad™ metrics have been employed to quantify match demands of outdoor team sports such as Australian football,[11] rugby league[13] and rugby union.[14] Positive correlations between collisions and PlayerLoad™ suggest that microtechnology can quantify external load for players that perform frequent tackles and hit-ups in addition to running demands.[13] There are also clear differences in total and relative PlayerLoad™ between positional groups that likely occur from different collision demands during matches. For example, PlayerLoad™ is greater in forwards (9.6 ± 2.0 $AU{\cdot}min^{-1}$) compared to adjustables (8.7 ± 1.3 $AU{\cdot}min^{-1}$) and outside backs (7.2 ± 0.8 $AU{\cdot}min^{-1}$),[13] who experience ~0.8, 0.5 and 0.2 $contacts{\cdot}min^{-1}$, respectively.[21] However, the reliability of many of these metrics during controlled exercise involving collisions is yet to be elucidated. The TE for relative PlayerLoad™ in the present study was 0.47 $AU{\cdot}min^{-1}$ and 0.56 $AU{\cdot}min^{-1}$ for the first and second bout, respectively. This variability is lower than the aforementioned differences between positional groups (1.5 – 2.4 $AU{\cdot}min^{-1}$), indicating that such differences can be detected with confidence using the modified protocol.

It has been suggested that PlayerLoad™ 2D (i.e. all non-longitudinal acceleration) and PlayerLoad™ slow (all accelerations that occur at < 2 $m{\cdot}s^{-1}$) can quantify load attributed to physical contact.[13] Our findings indicate that these metrics are sufficiently reliability to detect moderate changes in performance (CV% = 5.2-8.0%). The TE for these PlayerLoad™ derivatives (0.2-0.5 $AU{\cdot}min^{-1}$) are again lower than the differences between positions (2-3 $AU{\cdot}min^{-1}$) reported by Gabbett,[13] meaning differences in physical contact between players could be detected with these metrics. Furthermore, the PlayerLoad™ slow-ratio, which determines the relative contribution of low-speed (<2 $m{\cdot}s^{-1}$) accelerations to total PlayerLoad™ for each player, could provide a metric to compensate for individual variation in total PlayerLoad™ from differences in gait.[12] PlayerLoad™ slow-ratio appears adequately reliable to detect moderate to large differences in performance (CV% = 5.6–10.0%). However, whilst these measures are related to the number of collisions rugby players experience,[14] recent work by Hulin and colleagues [22] has challenged the utility of PlayerLoad™ metrics to quantify collisions given its greater association with changes of velocity. Indeed, higher PlayerLoad™ in forwards might not only be attributed to collisions but also the specific movements they perform compared to other positions.[23] Further research is needed to determine the sensitivity of PlayerLoad™ metrics to the types and intensity of collision before they can be used confidently.

Heart rate (%HR_{peak}) and RPE CV% was greater than the calculated moderate change, which suggests that internal load markers during the simulation are not as reliable as external load metrics. The aforementioned variation in tackle technique and associated variability in high-speed running performance might explain such cardiovascular responses to the simulation. Indeed, a significant relationship has been observed between high-speed running during rugby league small-sided games and measured cardiovascular and perceptual load.[24]

The study also sought to describe the external load associated with modified contact to examine if the simulation of match movement characteristics was improved. Total distance and high-speed running were reduced in the modified protocol compared to the previous version described by Waldron and colleagues (100 c.f. 105 $m \cdot min^{-1}$ and 23 c.f. 27 $m \cdot min^{-1}$, respectively),[5] which might also explain our observation of a lower

RPE and $\%HR_{peak}$. It is our contention that the modified physical contact influenced running behaviour,[10] with participants managing their effort to maintain performance during physiologically demanding collisions.[6,25,26] As high-speed running is largely self-regulated during the match simulation, participants can down-regulate this to avoid excessive fatigue, without the consequence of losing a match.[27]

Whilst total and high-speed running distance with the modified contact was lower than that previously observed during simulated performance (Table 3), it was closer to those reported from matches (90-100 and 15-17 $m \cdot min^{-1}$ for total and high-speed distance, respectively; Waldron et al., 2011). Furthermore, measured total PlayerLoad™ (~10 c.f. ~12 $AU \cdot min^{-1}$), PlayerLoad™ slow (~3 c.f. 5-6 $AU \cdot min^{-1}$), and PlayerLoad™ 2D (~6 c.f. 7-8 $AU \cdot min^{-1}$) during the modified simulation are similar to values reported in matches.[13] Taken in combination, the modified contact likely increased collision intensity to that more akin to match-play, and therefore reduced running distance in comparison to the previous simulation protocol.

The observed $\%HR_{peak}$ in this study (82%) is lower than those previously reported for simulated rugby league performance (87%),[5] albeit still within the range observed during competitive performance (~80-90 $\%HR_{peak}$).[2] Furthermore, RPE in the present study was ~3 AU lower (~13 c.f. ~16) than that reported by Waldron and colleagues.[5] Lower running loads observed during the simulation with modified physical contact could explain such results. Previously only amateur rugby players were recruited to analyse the reliability and validity of the match simulation protocol[5] whereas academy players made up ~47% of the participants in the current study. Such players participate in more frequent strength and conditioning sessions in addition to rugby training that results in greater aerobic capacity and sprint performance compared to non-elite players.[28] Therefore, it is to be expected that professional players would exhibit lower physiological and perceptual responses to similar external demands compared to amateur players.

Practical Applications

Practitioners should consider using the modified simulation protocol when requiring a controlled model to investigate the influence of training and nutritional interventions on match performance capabilities of rugby players. In particular, systematic changes in locomotive measures of total distance, low intensity running and peak sprint speed can be detected with confidence. Practitioners might also consider the use of the various PlayerLoad™ metrics, which are highly reliable. These measures are closer to those reported during rugby league match play than previous iterations of the RLMSP-i.[5]

Conclusion

The newly proposed rugby league movement simulation protocol using a modified collision provides a more appropriate replication of the external match demands associated with match play. Fundamental locomotive metrics and those capable of quantifying the load associated with physical contact were also reliable, with a lower variation between trials than that observed between competitive matches. Accordingly, we present an ecologically valid model that is capable of detecting changes in key physical performance measures of rugby league interchange players that might be observed after various intervention strategies.

REFERENCES

1. Sykes D, Twist C, Nicholas C, Lamb, K. Changes in locomotive rates during senior elite rugby league matches. *J Sport Sci*. 2011;29: 1263-1271.
2. Waldron M, Highton J, Daniels M, Twist C. Preliminary evidence of transient fatigue and pacing during interchanges in rugby league. *Int J Sports Physiol Perform*. 2013;8:157-164.
3. Kempton T, Sirotic, AC, Coutts AJ. Between match variation in professional rugby league competition. *J Sci Med Sport*. 2014;17:404-407.
4. Sykes D, Nicholas C, Lamb K, Twist C. An evaluation of the external validity and reliability of a rugby league match simulation protocol. *J Sports Sci.* 2013; 31:48-57.
5. Waldron M, Highton J, Twist C. The reliability of a rugby league movement-simulation protocol designed to replicate the performance of interchanged players. *Int J Sports Physiol Perform*. 2013;8:483-489.
6. Mullen T, Highton J, Twist C. The internal and external responses to a forward-specific rugby league simulation protocol performed with and without physical contact. *Int J Sports Physiol Perform*. 2015;10:746-753.
7. Clarke JS, Highton J, Close GL, Twist C. Carbohydrate and caffeine improves high intensity running of elite rugby league interchange players during simulated match play. *J Strength Cond Res*. 2016 Epub ahead of print.
8. Highton J, Mullen T, Twist, C. Knowledge of task end-point influences pacing and performance during simulated rugby league match-play. *Int J Sports Physiol Perform*. 2015; Epub ahead of print.

9. Bradley WJ, Hannon MP, Benford V, Morehen JC, Twist C, Shepherd, S., ... Close GL. Metabolic demands and replenishment of muscle glycogen after a rugby league match simulation protocol. *J Sci Med Sport*. 2017;20:878-883.
10. Norris JP, Highton J, Hughes SF, Twist C. The effects of physical contact type on the internal and external demands during a rugby league match simulation protocol. *J Sports Sci.* 2016; 34:1859-1866.
11. Boyd LJ, Ball K, Aughey RJ. Quantifying external load in Australian football matches and training using accelerometers. *Int J Sports Physiol Perform.* 2013; 8:44-51.
12. Barrett S, Midgley A, Lovell, R. PlayerLoad™: Reliability, convergent validity, and influence of unit position during treadmill running. *Int J Sports Physiol Perform.* 2014;9:945-952.
13. Gabbett T. Relationship between accelerometer load, collisions, and repeated high-intensity effort activity in rugby league layers. *J Strength Cond Res*. 2015;29:3424-3421.
14. Roe G, Halkier M, Beggs C, Till K, Jones B. The use of accelerometers to quantify collisions and running demands of rugby union match-play. *Int J Sports Physiol Perform.* 2016;16: 590-601.
15. Waldron M, Twist C, Highton J, Worsfold P, Daniels M. Movement and physiological match demands of elite rugby league using portable global positioning systems. *J Sports Sci*. 2011;29:1223-1230
16. Borg G. *An introduction to Borg's RPE scale.* Ithica, NY: Mouvement Publications; 1985.

17. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc*. 2009; 41:3-13.

18. Hopkins WG. Spreadsheets for analysis of controlled trials, with adjustment for a subject characteristic. *Sportscience*. 2006;10: 46-50.

19. Gabbett TJ. Influence of fatigue on tackling technique in rugby league players. *J Strength Cond Res*. 2008;22: 625-632.

20. Johnston RD, Gabbett TJ, Seibold AJ, Jenkins, DG. Influence of physical contact on neuromuscular fatigue and markers of muscle damage following small-sided games. *J Sci Med Sport.* 2014;17:535-540.

21. Cummins C, Orr R. Analysis of physical collisions in elite national rugby league match play. *Int J Sports Physiol Perform.* 2015;10:732-739.

22. Hulin BT, Gabbett TJ, Johnston RD, Jenkins DG. PlayerLoad^{TM} variables are sensitive to changes in direction and not related to collision workloads in rugby league match-play. *Int J Sports Physiol Perform.* 2018;15:1-21.

23. Delaney J, Cummins C, Thornton H, Duthie G. Importance, reliability and usefulness of acceleration measures in team sports. *J Strength Cond Res*. 2017 [Epub ahead of print].

24. Weaving D, Marshall P, Earle K, Nevill A, Abt G. combination of internal and external training load measures explains the greatest proportion of variance in certain training modes in professional rugby league. *Int J Sports Physiol Perf*. 2015;9:905-912.

25. Johnston RD, Gabbett, TJ. Repeated-sprint and effort ability in rugby league players. *J Strength Cond Res*. 2011;25: 2789–2795.

26. Johnston RD, Gabbett, TJ, Jenkins DG, Speranza MJ. The effect of different repeated-high-ontensity-effort bouts on subsequent running, skill performance, and neuromuscular function. *Int J Sports Physiol Perf*. 2016;11:311-318.
27. Waldron M, Highton, J. Fatigue and pacing in high-speed intermittent team sport: an update. *Sport Med*. 2014;44:1645-1658.
28. Johnston RD, Gabbett, TJ, Jenkins, DG. Applied sport science of rugby league. *Sport Med*. 2014;44:1087-1100.

Figure legend

Figure 1. Schematic of the RLMSP-i (not to scale), including the chronological ordering of audio cues. Y = yellow cone; R = red cone; B = blue cone; W = white cone.

Table legends

Table 1. The reliability of internal and external load during bouts 1 and 2 over two trials of the modified rugby league movement simulation protocol for interchange players (RLMSP-i).

Table 2. The reliability of PlayerLoad^{TM} variables during bouts 1 and 2 over two trials of the modified rugby league movement simulation protocol for interchange players (RLMSP-i).

Table 3. External and internal load responses during the both versions (modified and original) of the rugby league simulation protocol for interchange players (RLMSP-i) and match play.

Table 3. The reliability of internal and external load during bouts 1 and 2 over two trials of the modified rugby league movement simulation protocol for interchange players (RLMSP-i).

	Total distance ($m \cdot min^{-1}$)	High-speed ($m \cdot min^{-1}$)	Low-speed ($m \cdot min^{-1}$)	Peak speed ($km \cdot h^{-1}$)	$\%HR_{peak}$	RPE
Bout 1						
Trial 1 (± SD)	102.8 ± 2.4	25.0 ± 3.3	77.9 ± 3.8	24.3 ± 1.5	82.8 ± 6.6	14.4 ± 2.1
Trial 2 (± SD)	100.7 ± 3.1	24.1 ± 2.2	76.6 ± 2.6	23.7 ± 1.4	81.5 ± 5.1	12.7 ± 1.6
TE	1.4	2.0	1.7	0.9	3.9	1.9
CV%	1.3	8.0	2.2	3.7	4.8	13.7
SWC%	0.6	2.3	0.9	1.2	1.5	3.0
MC%	1.8	7.0	2.6	3.7	4.4	8.9
LC%	3.5	13.9	5.2	7.5	8.7	17.8
Bout 2						
Trial 1 (± SD)	100.3 ± 3.2	22.5 ± 3.3	78.6 ± 3.9	23.3 ± 1.9	80.8 ± 7.3	13.1 ± 1.8
Trial 2 (± SD)	100.7 ± 3.0	21.1 ± 4.0	79.6 ± 2.8	22.2 ± 2.6	78.9 ± 8.1	12.6 ± 0.9
TE	1.9	3.2	2.6	2.2	5.6	1.44
CV%	1.9	14.4	3.3	9.6	7.0	11.2
SWC%	0.6	3.4	0.9	2.0	1.9	2.2
MC%	1.9	10.3	2.6	6.1	5.8	6.7
LC%	3.7	20.5	5.2	12.2	11.7	13.5

SWC: Smallest worthwhile change
MC: Moderate change
LC: Large change

Table 4. The reliability of PlayerLoad^{TM} variables during bouts 1 and 2 over two trials of the modified rugby league movement simulation protocol for interchange players (RLMSP-i).

	Total PlayerLoad^{TM} (AU·min^{-1})	PlayerLoad^{TM} slow (AU·min^{-1})	PlayerLoad^{TM} 2D (AU·min^{-1})	PlayerLoad^{TM} slow-ratio (%)	PlayerLoad^{TM} distance-ratio (AU·m^{-1})
Bout 1					
Trial 1 (± SD)	10.0 ±1.3	3.3 ± 0.7	6.1 ± 1.0	32.9 ± 4.5	9.4 ± 1.8
Trial 2 (± SD)	9.8 ± 1.4	3.1 ± 0.5	5.8 ± 0.7	31.9 ± 3.8	9.5 ± 1.6
TE	0.5	0.2	0.5	3.3	0.8
CV%	4.7	7.3	8.0	10.0	8.2
SWC%	2.7	3.8	3.0	2.6	3.6
MC%	8.0	11.4	8.9	7.8	10.9
LC%	16.0	22.7	17.9	15.5	21.8
Bout 2					
Trial 1 (± SD)	9.8 ± 1.2	3.3 ± 0.6	5.8 ± 0.7	33.7 ± 4.3	10.2 ± 1.8
Trial 2 (± SD)	9.6 ± 1.5	3.1 ± 0.6	5.6 ± 0.8	32.7 ± 3.9	10.8 ± 2.3
TE	0.6	0.2	0.3	1.9	1.9
CV%	5.8	7.5	5.2	5.6	18.2
SWC%	2.9	3.6	2.8	2.5	4.0
MC%	8.6	10.9	8.3	7.5	12.0
LC%	17.1	21.8	16.7	15.0	24.0

SWC: Smallest worthwhile change
MC: Moderate change
LC: Large change

Table 3. External and internal load responses during both versions (modified and original) of the rugby league movement simulation protocol for interchange players (RLMSP-i) and for interchange players during match play.

	Modified RLMSP-i		**Original RLMSP-i**[5]		**Interchange match play**[5, 13]	
	Bout 1	**Bout 2**	**Bout 1**	**Bout 2**	**Bout 1**	**Bout 2**
Total distance ($m \cdot min^{-1}$)	102 ± 3	101 ± 3	108 ± 2	106 ± 3	96 ± 6	93 ± 5
Low-speed distance ($m \cdot min^{-1}$)	77 ± 3	79 ± 4	79 ± 4	78 ± 3	78 ± 8	78 ± 5
High-speed distance ($m \cdot min^{-1}$)	25 ± 3	22 ± 4	28 ± 2	27 ± 2	17 ± 6	15 ± 3
Peak speed ($km \cdot h^{-1}$)	24.0 ± 1.5	22.7 ± 2.3	26.7 ± 0.8	24.9 ± 1.7	26.9 ± 1.6	26.0 ± 1.4
PlayerLoad™ ($AU \cdot min^{-1}$)	10.1 ± 1.0	10.1 ± 1.0	-	-	12.1 ± 6.8	13.1 ±7.9
PlayerLoad™ slow ($AU \cdot min^{-1}$)	3.2 ± 0.6	3.2 ± 0.6	-	-	4.9 ± 2.7	5.9 ± 3.5
PlayerLoad™ 2D ($AU \cdot min^{-1}$)	6.0 ± 0.9	5.7 ± 0.8	-	-	7.5 ± 4.1	8.2 ± 5.0
Heart rate (%HRmax)	86 ± 5	84 ± 6	89 ± 3	86 ± 3	87 ± 5	88 ± 5

Note: PlayerLoad™ was not reported for original RLMSP-i